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WAVES OF SOUND AND SPEECH

AS REVEALED BY THE PHONOGRAPH.

BY

JOHN G. M'KENDRICK, M.D., LL.D., F.R.S.,

Professor of Physiology in the University of Glasgow.

THE SCIENCE LECTURE FOR 1896 TO THE PHILOSOPHICAL SOCIETY OF GLASGOW.

WITH NUMEROUS ILLUSTRATIONS AND TWO PLATES.

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1897.

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As many, both at home and abroad, who are interested in the Phonograph, have expressed a desire to read this Lecture, and have applied for copies, the Council of the Society kindly authorised its publication in separate form. The Lecture also appears in the *Proceedings* of the Society for 1896-97.

Fer. Where should this music be? i' the air, or the earth?

* * * *

Ste. * * * come on, Trinculo, let us sing.

* * * *

Cal. That's not the tune.

* * * *

Ste. What is the same?

Trin. This is the tune of our catch, played by the picture of Nobody.

THE TEMPEST.

WHEN the Council did me the honour of inviting me to deliver the Science Lecture for 1896, I thought that I could not do better than endeavour to give you an account of a research in which I have been engaged during the last two years. This research relates to the interpretation of the marks on the wax cylinder of the phonograph, and it has an important bearing on certain questions connected with physiological acoustics. Perhaps I ought to apologise to the physicists for so far invading their territory in this research. The work, some of the results of which I shall place before you to-night, is, no doubt, mainly of a physical nature. But sciences dovetail into each other so as to render it impossible to draw a clear line of demarcation between those that are closely allied. Of this we have an example in the close relationship that exists between many departments of physiology and of physics. Take, for instance, the department we term physiological acoustics. The physicist deals with sound as consisting of certain movements of matter occurring outside the physiological organism, and he investigates these movements as dynamical problems. On the other hand, it is the business of the physiologist to show how these movements affect the mechanism of the sense organ, the ear, how the filaments of the auditory nerve are stimulated, and how the impulses transmitted by the nerve to the brain are there, in a way absolutely unknown at present, translated into consciousness. No physiologist can attempt to

explain the mechanism of the ear without being acquainted with acoustics, nor can the physicist deal adequately with the phenomena of sound unless he takes into account the mechanism of the ear. Let me say to the physicists present that, if I have crossed into their territory in carrying out a purely physical research relating to hearing, I hope they will retaliate by pushing their researches into the physiological side, and apply their methods to the investigation of the mechanical phenomena in the body that end in a sensation of sound.

We have all more or less enjoyed, at one time or another of our lives, a certain amount of pleasure in the contemplation of wave movements. Rhythmic movement always gives pleasure, whether it be in the dance or in the undulations sweeping across a field of wheat when the winds of early summer are blowing. We have also, no doubt, stood on a rocky headland, or on the deck of an ocean steamer, and we have gazed with pleasure on the tumultuous action of the sea, as waves of many varying forms passed before our eyes. While the great rollers of the Atlantic have been distinctly visible, we have seen how their contours were moulded by numerous other waves, some possibly caused by the paddle-wheels or screws of passing vessels, by the eddies of wind that sweep over the surface of the water, or by the dip of a sea-bird's wing. While the infinite variety of form gave an abiding interest in the spectacle, the general feeling of rhythm probably contributed most to our feelings of pleasure.

The waves that we discuss in this lecture do not relate to movements that can be seen by the eye. Waves of sound appeal to the ear, not to the eye. They are invisible, and yet they are felt, because they excite variations of pressure on the drum-head of the ear; the effect of these variations is communicated to the nerve; the nerve carries the impulse to the brain, and we hear. Waves of sound differ in many respects from the waves which we see on the surface of water, and yet to explain sound waves we are often obliged to take our illustrations from the movements on the surface of water.

Let me, in the first place, lay before you a few general and elementary statements regarding waves of sound. A body that gives out sound is itself in movement.

The to-and-fro movements, say, of the limbs of a tuning fork, are called vibrations. These movements may be communicated to the air, or to liquids or solids. Let us confine our attention to the transmission of movements, vibrations, through the air, as it is by the medium of the air that we usually hear sounds. Each movement of the limb of the tuning fork causes first a greater pressure, and then, owing to the elasticity of the air, a smaller pressure on the air near it, and these variations of pressure are communicated through layer after layer of the air until they reach the drum-head of the ear. When there is an increase of pressure on the drum-head it is pushed in, and when the pressure becomes less, the drum-head passes back to its first position. These variations of pressure, usually periodic in character, as they occur in the air, constitute sound waves. So far they are purely physical movements, and if we could see the air as it is traversed by sound waves we would see shells, as it were, of condensed air alternating with shells of rarified air—that is to say, the condensed portions would correspond to positions of greater pressure, while the rarified portions would represent the positions of smaller pressure. The positions of greater pressure correspond to the crests of waves on the surface of water, and those of smaller pressure to the trough between two adjacent waves. As you are aware, we determine the length of a wave by taking any point on its surface and measuring the distance to a corresponding point on the next succeeding wave. Thus we say the length of a wave is from crest to crest, or from trough to trough. In like manner we say that the length of a wave of sound is the distance of any point of condensation or of rarefaction to a corresponding point in the next wave.

Think, again, of waves on the surface of water. These may vary in length, or in amplitude, or in form, as is well shown by

the diagram now thrown on the screen, from Mr. Sedley Taylor's interesting book on *Sound and Music*—

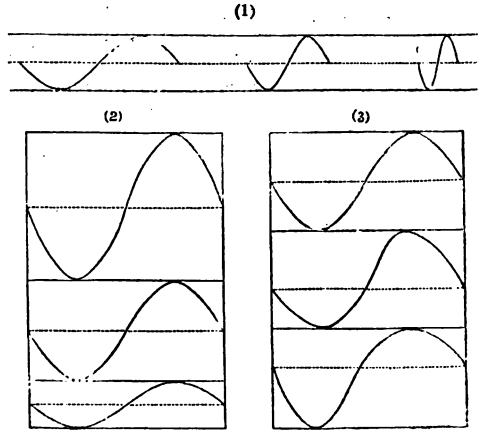

Fig. 1.—Waves.

Here you see, in (1) three waves the same in amplitude and form, but different in *length*; in (2) three waves the same in length and form, but different in *amplitude*; and in (3) three waves the same in length and amplitude, but different in *form*. Thus we may have waves varying much in length from long rollers to those of a few inches in length; we may have waves with high crests and deep troughs, or they may be merely feeble ripples on the surface of the water; finally, the waves may vary much in form, some having a slanting ascent and a less slanting descent, or they may have flat crests and shallow crests, or the reverse. Thus there may be an almost infinite variety of wave forms, although they may not differ as to wave length and wave amplitude.

This illustration must now be applied to our conceptions of waves of sound. Thus a sounding body, such as a vibrating tuning fork, may cause waves, each of which is exactly similar to any one of the series, or to all in the series. If we cause the tuning fork to record its vibrations on a moving surface, such as a drum moved with great regularity by clock work, and covered by paper blackened in a sooty flame, we obtain tracings like those now thrown on the screen:—

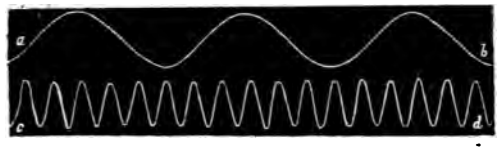

Fig. 2.—Tracings of the Vibrations of a Tuning Fork—10 vibrations per second. *a*, *b*, cylinder moving rapidly ; *c*, *d*, cylinder moving slowly.*

These we may term simple waves, and they are caused by pendular vibrations—that is to say, by movements like the periodic oscillations of a pendulum. Apply this again to help out the conception of a wave of sound. The crests would correspond to the condensations, or greater pressures, and the troughs to the rarefactions, or lesser pressures.

From these simple waves we may now form compound waves. Thus I sound this large fork by drawing a fiddle bow across its prongs, and it gives out a strong, deep tone. This tone is caused by varying pressures on the drum-head, as I have explained. Then I sound this other fork, which gives out the octave of the first. It sets up a series of waves of half the length of those of the first, and the resultant tone is caused by a compound wave made up of the two waves, the form of which (if the two waves started simultaneously) is shown in the diagram now on the screen :—

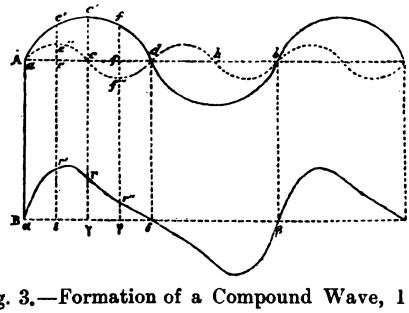

Fig. 3.—Formation of a Compound Wave, 1 : 2.

You observe that the lower wave is produced by combining the two upper waves. In like manner I now sound a fork which vibrates three times as fast as the first. The resultant tone now

* M'Kendrick's "Physiology," Vol. I., Fig. 236, p. 385.

corresponds to a wave built up of three waves, as now shown on the screen :—

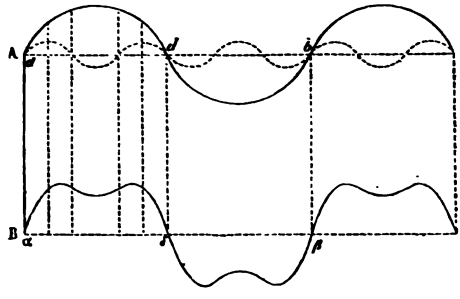

Fig. 4.—Formation of a Compound Wave, 1 : 3.

You observe the resultant wave produced by 1 : 3 is quite unlike that formed by 1 : 2. In this manner many wave forms may be produced. Thus you see in the next figure two simple waves represented by the thin lines, and the resultant wave form by the thick lines. In (1) and (2) the simple waves have the same length, but they differ in amplitude. Again, in (1) the troughs of the waves are on the same side of the dotted line which indicates the line of mean pressure, while in (2) the crest of the one wave is opposed to the trough of the other. In both (1) and (2) the waves start at the same moment, but in (3) that is not the case.

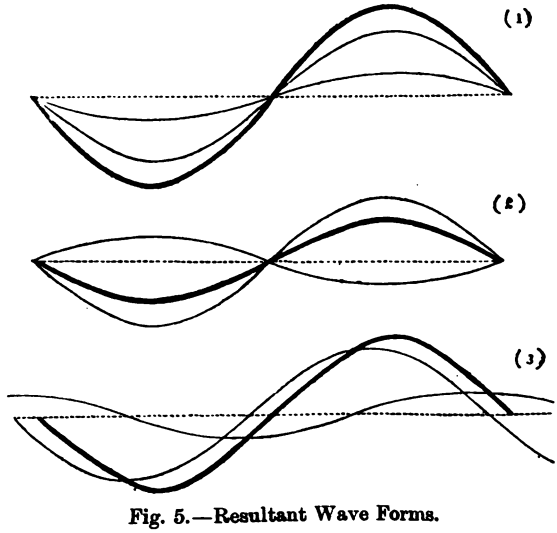

Fig. 5.—Resultant Wave Forms.

Suppose, again, two waves equal in amplitude started at the same moment, but so that the crest of the one corresponded to the trough of the other, it is evident the one would neutralise the other, and there would be no displacement. This is called the phenomenon of interference. Complete interference is shown in the next figure.

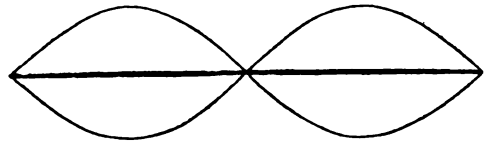

Fig. 6.—Interference.

The very complex form that may be produced by the combination of three waves is illustrated in the next figure. Here the wave 2 is the half of wave 1, and wave 3 is $1\frac{1}{2}$ that of 2, or wave 3 is the one-third of wave 1. In other words, the lengths of the waves are as 1, 2, and 3. The resultant wave form is seen in 4. The diagram also shows how the wave in 4 has been plotted out. Take the vertical line from a' in 1, 2, and 3, and measure in each case from the horizontal line to the top of the curve. Add the three measurements, and the sum gives the point of the curve of 4 above b', and so on for any point on the curves of 1, 2, and 3. The measurements of the three lines, if above or below the horizontal lines, are added together, and the corresponding point is taken for curve 4; on the other hand, if one measurement be *above*, and two or more be *below* the horizontal line, then from the greater measurement the sum of the two smaller ones is taken, and the mean indicates the position of the point on the curve 4.

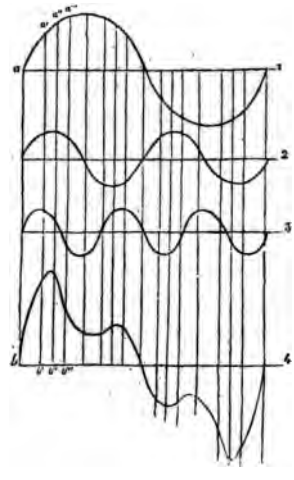

Fig. 7.—Superposition of Three Waves.

Another form of resultant wave is shown in the next figure. By combining A and B, C is produced.

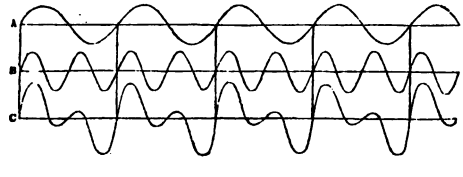

Fig. 8.—Compound Wave Form.

The form of the compound wave, however, will depend not only on the number and amplitude of the waves entering into its composition, but also on the relation of the phases of the vibrations of the constituent waves. Thus, if we start three waves at the same moment, we will obtain one resultant wave form; but we can vary

this by starting the waves at different times. This is well shown in a diagram from von Helmholtz, now on the screen :—

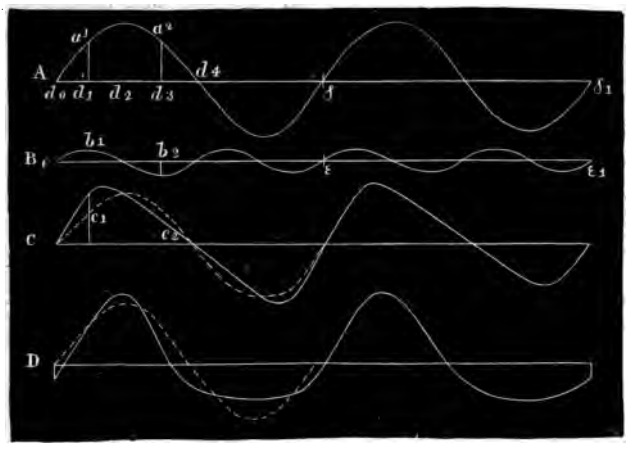

Fig. 9.—Waves, with Variation of Phase.

"If we superpose the two pendular vibrations A and B first with the point e of B on the point d_0 of A and next with the point e of B on the point d_1 of A, we obtain two entirely distinct vibrational curves C and D. By further displacement of the initial point c, so as to place it on d_2 or d_3, we obtain other forms." *

In this way a great variety of wave forms may result from combinations of two waves, as these differ in *length*, in *amplitude*, and in *phase*. Three such combinations are seen in the next figure, in which the thick line represents the resultant wave.

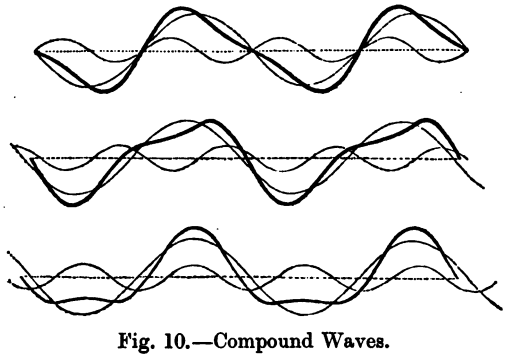

Fig. 10.—Compound Waves.

* VON HELMHOLTZ. *Sensations of Tone*, p. 174.

Thus we can now understand what is meant by a compound wave, and you will appreciate the statement that compound waves may be very complex in character. If you look at the curves showing the resultant waves, you will see that they represent, in a way, the character of the variations of pressure made on the drum-head. With simple pendular waves, as in Fig. 1, the drum-head moves out and in with perfect regularity, like the movements of a pendulum. The physiological effect of such simple pendular vibrations is a sensation of a pure tone, such as you hear when I bow this tuning fork. But if a compound wave falls on the drum-head, it is not so easy to follow with the imagination the variations of pressure. While these variations occur in regularly recurring intervals of time so as to give the sensation of the pitch of the fundamental tone, the movement may not be uniform on each side of the median line, indicating the position of repose of the drum-head, like the swing of a pendulum. Thus the drum-head may move in, owing to the increase of pressure, faster than it moves out, or the reverse; or it may move in a little distance, then return again to the starting point and again move in, and it may return to the position of rest after one or more to-and-fro movements. Again, it may be pushed in the maximum distance, and remain in that position for a short time, and then return to the original place of repose. Thus the characters of the variations of pressure may vary to a remarkable degree—to a degree, with a very complex sound, that is to us almost inconceivable; but we may be sure that these variations of pressure will be faithfully followed by the drum-head, and communicated by it to the deeper ear. When a compound wave thus falls on the ear, the result is a sensation of sound of a certain quality, or timbre, or clang, and we say that we hear the sound of various musical instruments, as in a brass band or an orchestra, or the sound of a particular instrument, a trombone, a flute, a harp, a clarionet, or the sound of a well-known voice that we can distinguish from all others.

The attempt to record graphically the vibrations of bodies emitting sound has always been a fascinating occupation for

physical observers. Thus it is easy, by the method suggested in 1807 by Thomas Young * and carried out by Wertheim † in 1842, to obtain a record of the vibrations of a tuning fork, as shown in Fig. 1. Chronographs, such as you now see in operation, are found in every physical and physiological laboratory. Many attempts have been made to obtain tracings of the vibrations of membranes and of glass or metallic discs. In 1856, Léon Scott ‡ invented the well-known phonautograph, an image of which is now thrown on the screen, and which may be regarded as the precursor of the phonograph.

Fig. 11.—The Phonautograph of Léon Scott.

The sounds are collected by the barrel-shaped part of the apparatus, and transmitted to a thin membrane to which a style is attached. The latter is brought against the blackened surface of the rotating drum, and a tracing of the vibrations is thus obtained. I throw

* TH. YOUNG. *A Course of Lectures on Natural Philosophy and the Mechanical Arts*, 1807, Vol. I., p. 191.

† G. WERTHEIM. *Recherches sur l'elasticité*, 1er mem.

‡ E. L. SCOTT, *Comptes rendus*, t. 53, p. 108.

on the screen a beautiful series of tracings taken by Dr. Koenig, Paris, by an instrument of this kind. (Fig. 12.)

Donders,* in 1870, applied the phonautograph to the investigation of the curves produced by the sounds of vowels. Next came the logograph of Barlow,† by which curves were obtained by the vibrations of a thin membrane of gold-beater's skin. These curves represented the varying pressures of the expelled air taken

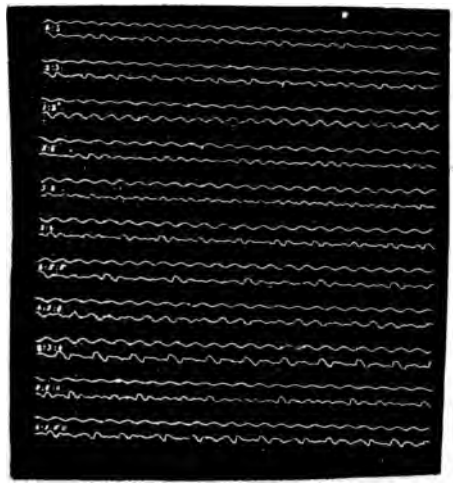

Fig. 12.—Vibrations of the Membrane of the Phonautograph under the influence of a series of organ pipes, the ratio of the vibrations of which are indicated by the figures. Above each tracing is a tracing of the vibrations of a tuning fork of 512 vibrations per second.

as a whole, but did not indicate pitch. About 1862, Koenig‡ introduced the method of manometric flames, and flame pictures of

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* DONDERS. *De physiologie der spraachklanken in het bijzonder van die der nederlandische taal.* Utrecht, 1870.

† BARLOW. *Trans. of Royal Society*, 1874.

‡ RUDOLPH KOENIG. *Annalen der Poggendorff*, t. CXXII., pp. 242, 660. 1864. See also *Les Flammes Manométrique in Quelques Expériences d'Acoustique.* Paris, 1882.

vibrations were thus obtained. In 1876, Clarence J. Blake* employed the human *membrana tympani* as a logograph. In the same year, Stein† carried out a method by which he photographed the vibrations of tuning forks, strings, &c., by attaching to them plates of blackened mica perforated by small holes. A beam of light passing through a hole was allowed to play on a sensitive photographic plate moving with uniform velocity. There was thus recorded a curve representing the combined motions. All of these instruments made it possible to record vibrations, but the sound could not be reproduced from the tracings thus obtained. This was accomplished by Edison when he invented the phonograph in 1877. In 1878, Fleeming Jenkin and Ewing‡ succeeded in obtaining tracings of the records of vowel sounds on the tinfoil phonograph, and the curves were submitted to harmonic analysis. Shortly afterwards, and in the same year, 1878, E. W. Blake§ succeeded in photographing the minute vibrations of a circular ferrotype plate screwed to a telephone mouthpiece by attaching a small mirror to the back of the plate and directing a reflected beam of sunlight on a moving photographic plate. Since that time, the marks on the tinfoil of the first phonograph have been scrutinised by Grützner, Mayer, Graham Bell, Preece, and Lahr.‖ The imperfections of the tinfoil phonograph made progress impossible for ten years (from 1878 to 1888), during which time, however, Edison, Graham Bell, and others were engaged in working out the mechanical details of the wax-cylinder phonograph. The subject was then

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* Blake, C. J. *Archiv. of Ophthalmology and Otology*, Vol. V., p. 1, 1876.

† Stein, S. Th. *Die Photographie der Tone. Poggendorff's Annalen*, 1876, p. 142.

‡ Fleeming Jenkin and Ewing. *On the Harmonic Analysis of certain Vowel Sounds. Trans. Roy. Soc. Ed.*, Vol. XXVIII., p. 145.

§ Blake, E. W. *A Method of recording Articulate Vibrations by means of Photography.* Amer. Jnl. of Science and Arts, 3rd Series, Vol. XVI., p. 54.

‖ Referred to in *The Telephone, the Microphone, and the Phonograph*, by Count du Moncel. London, 1884. See also *The Speaking Telephone and Talking Phonograph*, by G. B. Prescott. New York, 1878.

taken up by Hermann,* and he succeeded in obtaining photographs of the vibrations of the vowel sounds, a beam of light reflected from a small mirror attached to the vibrating disc of the phonograph being allowed to fall on a sensitive plate while the phonograph was slowly travelling. The curves thus obtained were very beautiful, and they present a striking resemblance to some of Koenig's flame pictures. In 1891, Boeke,† in a laborious microscopical research, measured the transverse diameters of the depressions on the wax cylinder at different depths, and from these measurements calculated the depths of the curves. He then reconstructed the curves on a large scale. During the present year, William Hallock ‡ has photographed the flames of an apparatus somewhat similar to the analyser of Koenig. Manometric capsules were attached to eight resonators, corresponding to the eight tones of a harmonic series, and when the flames were lit, by a device of swinging the camera in front of them, a photograph was obtained of the eight bands of flame as modified by singing the vowels in front of the resonators.

Recently also Pipping,§ of Helsingfors, has traced and analysed the curves obtained by a kind of phonautograph constructed on the type of the drum-head of the ear, and R. J. Lloyd,‖ of Liverpool, has written two valuable papers on the interpretation of the tracings obtained by Pipping and by Hermann.

The phonograph I now show you was one of the first made in

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* HERMANN. *Ueber das Verhalten der Vocale am neuen Edisonischen Phonographen, Pflüger's Archiv*, Vol. XLVII., 1890, p. 42; also *Phonophotographische Untersuchungen*, Vol. 45, p. 582; 47, p. 47; 53, p. 1; 58, p. 255; 61, p. 169.

† BOEKE, *Microscopische Phonogrammstudien, Pflüger's Archiv*, Vol. L., 1891, p. 297.

‡ HALLOCK. *Photographic Record of Sound Analysis. The American Annual of Photography* for 1896.

§ PIPPING. *Om Klangfärgen hos sjunga Vokaler;* also *Zeitschrift für Biologie*, Vol. XXVII., p. 1, and XXXI., p. 524; also *Acta Societatis Scientiorum feunicæ*, T. XX., No. 11.

‖ R. J. LLOYD. *The Genesis of Vowels*, and *The Interpretation of the Phonograms of Vowels.* Journal of Anatomy and Physiology. Vol. XXXI., New Series. Vol. XI., Part II., Jan. 1897. See also Dr. Lloyd's paper on *Phonetische Studies*, Vol. IV.

this country. It was constructed by the late Professor Fleeming Jenkin in 1876. It represents—

Fig. 13.—The Tinfoil Phonograph.

the phonograph in its simplest form. You observe how the drum travels from side to side, as in the phonautograph. The drum has a deep spiral groove, the thread of which corresponds to that of the spindle on which the drum rotates, and it is covered with thin, soft tinfoil. The membrane has fixed firmly to its centre a stout little marker having a chisel-shaped edge. When sound waves fall on the membrane, it vibrates, and as the drum is rotated, the edge of the needle pushes in the tinfoil into the spiral groove, and it makes a series of indentations corresponding to the variations of pressures produced by the sound waves. When the sound is reproduced, we run the point of the needle over these indentations by turning the drum, and the varying pressures on the needle point caused by the indentations act on the membrane, and reproduce the sound. Thus this simple mechanism records the *number* of vibrations, corresponding to pitch, the relative *amplitude* of the vibrations, corresponding to intensity or loudness, and the *form* of the vibrations which has reference to the quality of the sound.

Since this remarkable invention first appeared, the phonograph

has been improved so as to make it now a valuable scientific instrument. Many are too apt to think of it as an amusing toy, or as an apparatus that will serve the practical purpose of a shorthand writer. It is both amusing and practical, but it is much more. It is now a scientific instrument worthy of a place in physical and physiological laboratories beside other instruments of scientific research, and those employed for demonstration in teaching. It merits this position because it makes it possible to study some of the phenomena of sound in a manner otherwise unattainable.

Since 1877, the phonograph has been immensely improved, and we now have it in the form that you see before you. The machine used in this country is so geared that the wax cylinder, $6\frac{7}{8}$ inches in circumference, makes two revolutions in one second, while the spiral grooves described on the cylinder are $\frac{1}{200}$th inch apart. A spiral line about 136 yards in length may be described on the cylinder, and the recording or reproducing point travels over this distance in about 6 minutes.

I have also used the American model, now also before you, which resembles in all essential particulars the one I have just described, except that the grooves are $\frac{1}{100}$th inch apart, instead of $\frac{1}{200}$th inch.

The mechanism by which the glass disc or diaphragm communicates its movement is shown by means of the large model now before you. When sound waves fall on the glass disc, the latter is subjected to variations of pressure, as I have already explained. From the centre of the glass disc there comes a rod which passes to the end of a lever, and to this lever a counterpoise is attached. The end of the lever carries a sapphire point which, like a gouge, cuts a spiral groove on the surface of the wax cylinder. When there is increased pressure on the disc, the inclination of the edge of the gouge is directed downwards at such an angle with the surface of the wax cylinder as to cut a groove of a certain depth; but when the pressure becomes less, the angle is changed, the gouge cuts more in a horizontal direction, and the groove ploughed out is not so deep. Consequently as with each

vibration of sound we have, as I have already explained, increased pressure and diminished pressure. A series of marks of an oblong form are made in the bottom of the groove, each little mark

Fig. 14.—The Phonograph. English Model.

corresponding to a vibration. The number of such marks therefore in a given distance—which, when the velocity of the movement is taken into account, represents a certain interval of time, say the $\frac{1}{50}$th of a second—corresponds to the pitch of the note; the depth of the marks corresponds to the intensity of the vibration;

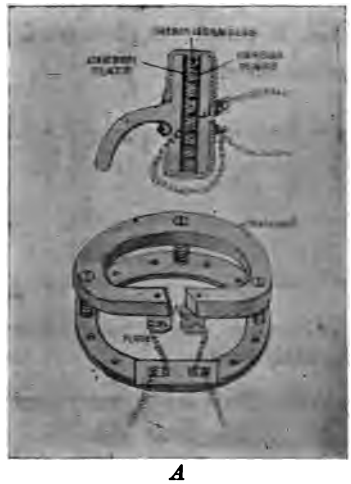
and the form of the marks to the form of the vibration. Again, suppose a note is sung *diminuendo* to *crescendo* and again to *diminuendo*, the depth of the groove will vary according to the intensity, at first shallow, gradually becoming deeper till the maximum depth has been reached, and again becoming more and more shallow. These marks, therefore, on the wax cylinder are the representations of the mechanical effects of the vibrations in all respects—number (pitch), depth (intensity or loudness), form (quality). It will be evident, therefore, that if we run over these marks again with the reproducing point, the glass disc will again vibrate to the impulses received by the ups and downs on the cylinder as to reproduce faithfully, but with diminished intensity, the original sound. It is, therefore, an investigation of great interest to study these marks, to reproduce them on such a scale as to enable us to study their form, and to let us see the ups and downs as we would do, suppose we could make a longitudinal section along the bottom of the groove and looked at the marks sideways.

Before we set ourselves to the study of these marks, let me bring under your notice certain other branches of the investigation. In the first place, we may, to a wonderful extent, increase the volume of tone or loudness of the phonograph by the use of resonators. No doubt the *quality* of the tones is best appreciated by carrying the vibrations directly to the vicinity of the drum-head of the ear, as is usually done, by fine tubes, but this method is not always agreeable, and the pleasurable effect is sadly marred by the friction noises. Still the fact that tones are heard best in this way, *as regards their quality*, proves to my mind that the marks on the wax cylinder are accurate representations of the varying intensities of the pressures caused by the sound waves. Resonators, such as the large one you now see, increase the volume of tone, and you will notice how accurately the tones are reproduced. I cannot to-night enter on a consideration of the theory of the action of resonators. It is by no means easy to explain how such a one as you see, and by which you now hear, increases the volume of the tone.

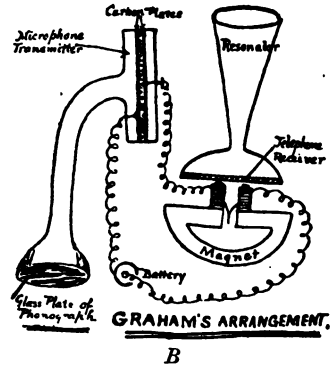
Another method is that of Mr. Alfred Graham, which I now show you. A specially constructed carbon transmitter is hung over the phonograph, and a tube passes from the glass disc of the latter to the carbon plate of the transmitter. A current is sent

Fig. 15.—Phonograph furnished with a large tin-plate resonator (12 feet in length, 3 feet in diameter at wide end).

through the transmitter and thence to a specially arranged loud speaking telephone, before which, you will observe, I have a very large resonator. When the variations of pressure, corres-



A



B

Fig. 15A.—Graham's Variable Resistance Apparatus applied to the Phonograph. *A*, Transmitter above, Telephone below. *B*, Applied to the Phonograph.

ponding to the sound waves emitted from the glass disc of the phonograph, act on the carbon plates and carbon particles of the transmitter, more or less resistance is offered to the current. These variations of resistance act on the telephone, and the sound is reproduced with great intensity by the latter. You will understand Graham's arrangement by the diagram now thrown on the screen, while you hear a trombone solo thus intensified. By this device energy is introduced—that of the battery,—and I feel sure that it is in this direction that further developments may be expected from the phonograph.

Now, let us see what we can make of the marks. I have endeavoured to study the marks on the wax cylinder in three different ways—by casts, by photographs, and by mechanical devices.

As regards the first method, taking casts, which was also attempted by Hermann and Boeke, the results were not satisfactory. The most efficient method followed by me was to paint in the cylinder, with a camel-hair brush, a layer of celloidin dissolved in ether. This soon hardened, and the film could then be peeled off. The thin film thus obtained was then inverted on the stage of a microscope, and the marks were seen in relief. A photograph of the marks thus obtained is now on the screen—

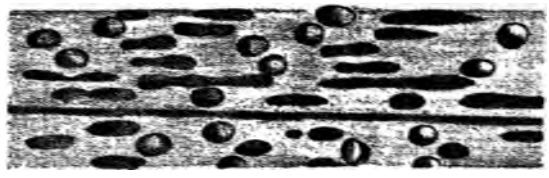


Fig. 16.—Celloidin Cast (Magnified) of Marks on Wax Cylinder. Portion of record of a military band.

The depressions are well seen, and their differences as regards length are obvious. The method has the disadvantage of flattening out the marks.

I took numerous photographs, with the aid of the microscope and camera, of portions of the surface of the cylinder on which

were records of many instruments and of the voice. I now show you on the screen examples of such records :—

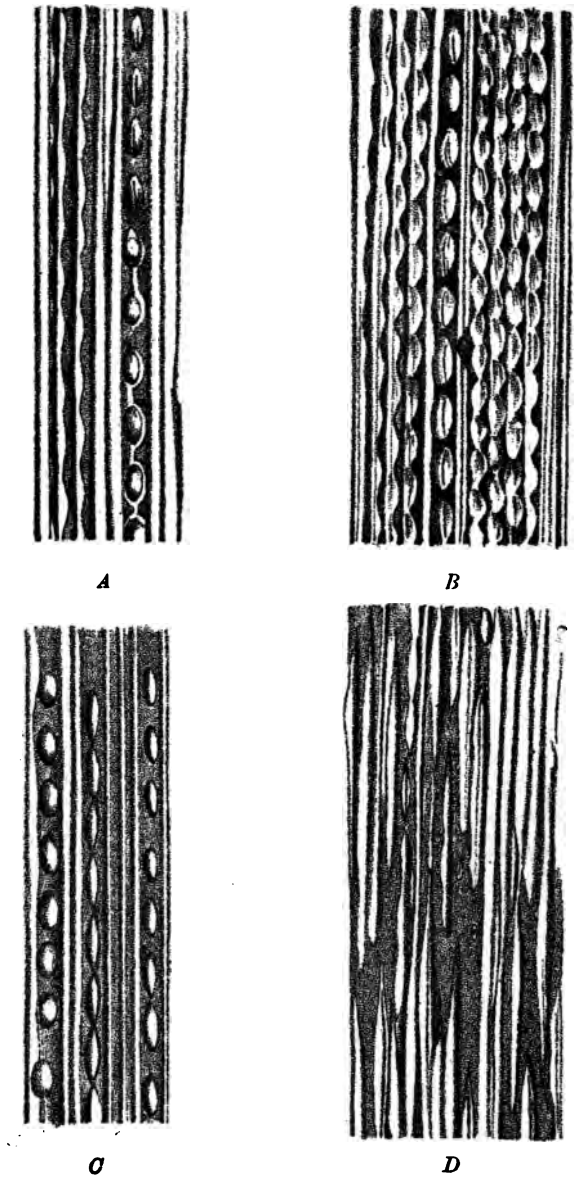


Fig. 17.—From Photographs of portions of the surface of the Wax Cylinder. *A*, Violin. *B*, Flute. *C*, Vowel *o*. *D*, Full Organ.

Each figure, from above downwards, represents the $\frac{1}{5}$th of an inch on the surface of the wax magnified fourteen diameters. The grooves seen in each figure are, on the wax cylinder, $\frac{1}{200}$th inch apart, and the length of the groove, from above downwards, represents in time the $\frac{1}{64}$th second; that is to say, when each tracing was recorded, the sapphire point of the recorder travelled over the distance represented in magnified proportions in the $\frac{1}{64}$th part of a second. By counting the number of indentations or marks, which in a photograph have a curious appearance of being in relief, one can at once determine approximately the pitch of the tone, the vibrations of which make the impression. The tones highest in pitch were obtained from the piccolo and the xylophone. Here the pitch was about 1,920 vibrations per second. In Fig. 17 (*A*) we have a picture of the vibrations produced by the tones of the violin, and it will be seen that they vary in character. Sometimes the marks are a little apart, and at other times they blend into each other, the mark widening out as the receding point cut into the wax and then contracting as it receded. It is to be born in mind that even when the glass disc is not vibrating, the recorder ploughs a groove on the cylinder, and when the glass disc vibrates each vibration cuts deeper into the groove. The figure of the vibration of the tones of a flute (*B*) shows moniliform markings, indicating that the disc may not, in some instances, return to its position of rest for a short time. Sometimes the intensity of the tone is so great as to cause, after each deeply ploughed groove (as will be seen in the figure of the vibrations of the tones of an organ, *D*), a rebound lifting the recorder up to the surface of the cylinder, or even off the surface altogether. This is the explanation of the smooth spaces between the ends of the individual marks.

To obtain a mechanical representation of the curves is a very difficult matter. The difficulties were so far overcome by the device of Jenkin and Ewing with the tinfoil phonograph. The method followed by these observers, which was entirely mechanical, was to cause the disc of the phonograph to record its movements

on a drum moved at the same rate as that of the cylinder. As I have already mentioned, Hermann photographed the oscillations of a beam of light reflected from a small mirror connected with the disc of the phonograph, the whole apparatus moving slowly. My method consists in the adaptation of a light lever to the phonograph itself, and so arranged that it (the point of the marker) would travel over all the ups and downs of the phonographic curve on the wax cylinder at an extremely slow rate. The obvious objection to any method of directly recording the ups and downs of the lever is that the inertia of the lever might cause extraneous

Fig. 18.—Specimen of curves obtained by Professor Hermann. The vowel *a* sung on the note *e*.

vibrations, while, at the same time, the smaller marks on the wax cylinder might be missed. These objections, however, were removed by reducing the friction to minimum, and by moving the phonograph cylinder so slowly as to make the movement almost invisible to the naked eye. In this way inertia ceases to give trouble. The first arrangement gave curves of very small amplitude, a specimen of which I now show you.

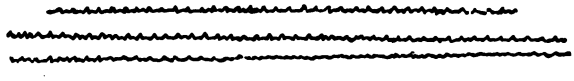


Fig. 19.—Specimen of curves taken with a simple lever. The curves were from the record of a cornet solo.

Various mechanical arrangements were employed, some of which I described to the Royal Society of Edinburgh in February last.*

My attention has since been directed to perfecting a mechanism for obtaining a record of the vibrations, and I wish to acknowledge the great assistance derived from the ingenuity and mechanical

* M'Kendrick, *Observations on the Phonograph, Trans. Roy. Soc. Edin.*, Vol. XXXVIII., Part IV., No. 22.

skill of Mr. Reid and Mr. Kean, of the well-known firm in Glasgow known by the name of "James White." The instrument now before you (and put into operation by Mr. Kean), which I shall call a *phonograph-recorder*, traces out, on a large scale, the curves of the indentations on the wax cylinder corresponding to each vibration of sound, and it does so in a way that seems to be highly satisfactory. It is now an instrument that can be used by other workers in this difficult department of research, and I hope that some of the younger physiologists and physicists will take the matter up, and apply it to an extent that, with numerous avocations and with calls to other branches of physiological research, I can never hope to overtake.

The essence of the method consists in (1) driving, at a very slow rate, the mandril carrying the wax cylinder of the phonograph on which a record has been taken. It is well to obtain well-marked records, and if possible taken specially for purposes of investigation, and at the time carefully noting the speed of the phonograph. The best speed I have found to be, as nearly as possible, that of one revolution in half a second. I now drive the mandril, *a*, as shown on the plate, by means of a small electric motor, *b*, worked with one or two Obach cells of the Q type, b^{I}, and the speed of revolution is one revolution in eight minutes, or nearly 1,000 times slower than the speed at which the mandril rotates when the phonograph is giving out tones. This slow speed gets rid of the inertia of the recording lever now to be described. (Fig. 20.)

On the ring bearing the apparatus for holding the glass diaphragm, which has been removed, there is attached a light lever, cc^{I}, made of aluminium, rectangular in section, and so placed as to have the shorter ends above and below. This lever has its fulcrum in a well-made axle and pivot joint, c^{III}. It is continued backwards, as seen in the Fig. (p. 27), so that a small weight may, if necessary, be used as an equipoise. About 5 mm. from the pivot end of the lever, there is passing off from it, at right angles, an upright rod c^{IV}, shod on its lower end with the usual sapphire point of the reproducing phonograph. When this

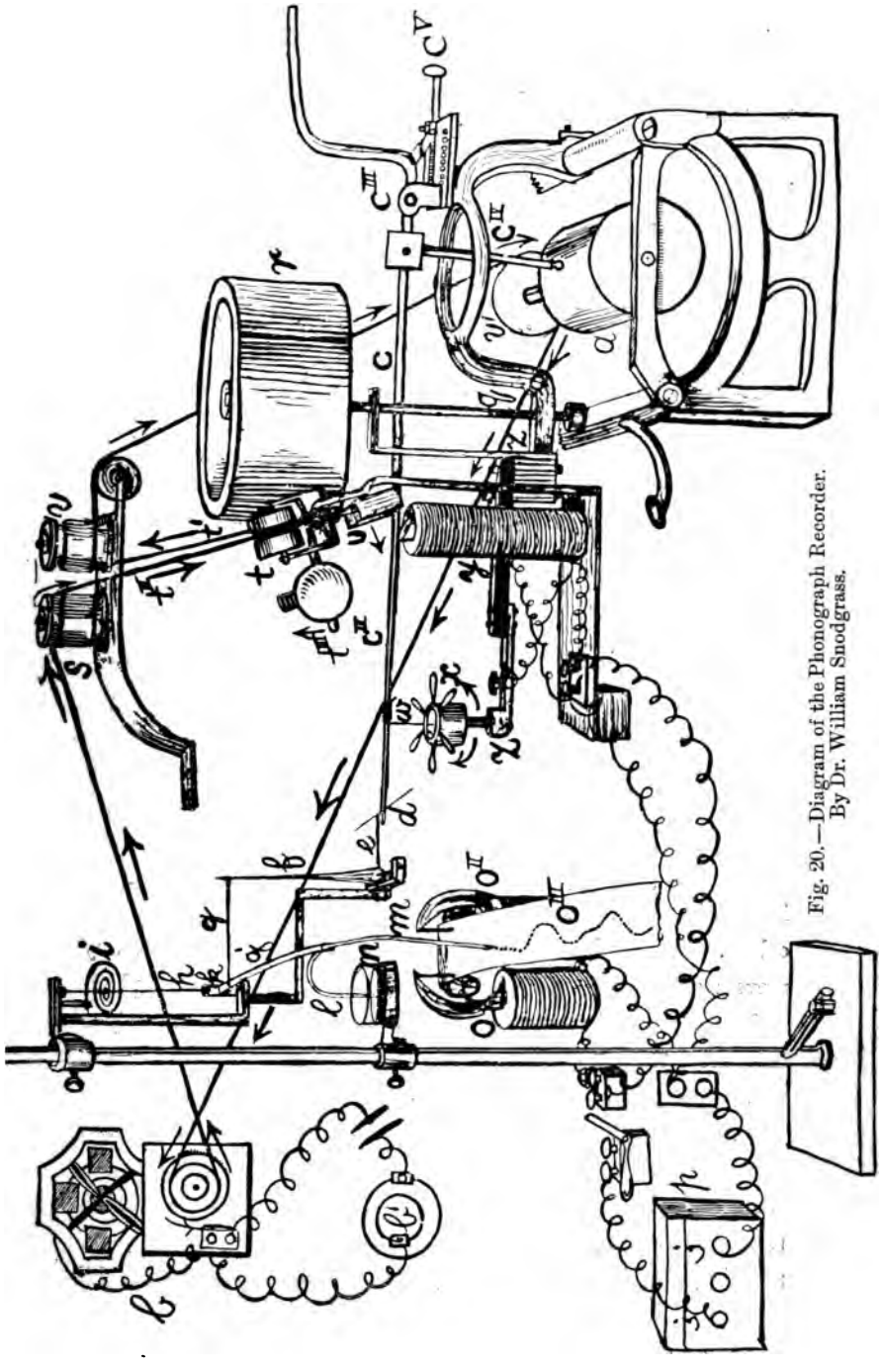


Fig. 20.—Diagram of the Phonograph Recorder.
By Dr. William Snodgrass.

point rests on the wax cylinder in the groove, and the cylinder moves slowly, as already described, it will be evident that this lever will move up and down, as the recording point slowly moves over the elevations and depressions on the cylinder, and that as the long arm of the lever c^{II} in plate is 205 mm. in length the amplification at the point of the lever will be considerable.

To secure still greater amplification, the point of this aluminium lever, which we will call the *first lever*, rests on a horizontal stiff rod, *d*, 80 mm. in length, which is attached transversely to the short arm of another lever, to be termed the *second lever*. The fulcrum of this second lever is also a well-made axle and pivot arrangement, the short arm, *e*, 25 mm., is horizontal, while the the long arm, *f*, 110 mm., is vertical. In this way the movements of the first lever are communicated to the second lever, and they are thus amplified a second time.

From the point of the second lever a thin rigid wire, *g*, passes transversely, 80 mm., to be attached to a thin slip of brass, *g'*, bearing a fine glass syphon, like the syphon, *m*, used in the well-known syphon recorder of Lord Kelvin. This strip of brass bearing the syphon is attached to an upright rod, *h*, bearing a circular weight at its lower end, *k*, delicately pivotted above and below, and having a fine watch spring attached to its upper end, *i*. The syphon is placed horizontally, with the longer limb, *m*, towards the front of the apparatus, and with the shorter limb, *e*, dipping into an ink-pot, *n*. The ink used is a filtered solution of an aniline colour. It will be evident, on looking at the plate, that any movement of the second lever is thus communicated to the syphon, and that oscillations of the syphon are controlled by the weight and the spring already described. The amplification of the movement is also greatly increased.

The paper on which a tracing is taken is rolled out below the long end of the syphon by an ingenious electro-motor arrangement recently devised for Lord Kelvin's syphon recorder. It will be remembered that, in the usual form of Lord Kelvin's syphon recorder, the ink, electrified by the well-known "mouse-mill,"

spurts out on the band of paper, o^{III}, and thus a line is recorded in a series of dots and without friction. The new arrangement gets rid of the mouse-mill. The mechanism, oo^{II} (electro-magnetic), which draws the paper forwards, at the same time vibrates up and down through a very short distance, and thus, at short intervals of time, brings the paper against the minute drop of ink at the end of the syphon. Thus the end of the syphon does not rub on the paper, and there is practically no friction. The tracing appears as a line formed of a number of minute dots, the distances between which correspond to the rate of vibration of the apparatus.

The apparatus is worked by a storage cell, *p*, of about 6-8 volts, and it runs at such a speed that 24 feet of paper are rolled out during the time of one revolution of the phonograph. Consequently, on a length of 20 feet of paper, we obtain a record of all the vibrations that were recorded on $7\frac{7}{8}$ths inch of surface of cylinder, or in a period of half a-second. One foot of paper would therefore represent $\frac{1}{40}$th second, and one inch would represent $\frac{1}{480}$th of a second.

The amplification vertically is nearly 1,000 times, but in the direction of length it is only about 35 times magnified. To obtain the tracings so as to increase the amplification in length to correspond to the amplification in height—that is to say, to 1,000 times—it would be necessary either to drive the phonograph 36 times slower, or a speed of one revolution in about 5 hours, or to roll out the paper 36 times faster, or about 864 feet in 8 minutes, instead of about 24 feet. Manifestly either of these devices would be very inconvenient, and it is unnecessary to attempt to carry these out, as for purposes of analysis it does not matter. In the description of the few curves of phonographic records I have seen taken by Hermann and Pipping, nothing is said in explanation of the fact that the tracings are not amplifications to scale of the true marks on the phonographic cylinder. I show you here (1) a tracing of the vibrations of a bugle, taken by my apparatus, giving an amplification about 1,000 times vertically, and 35 times in a linear direction, and (2) a tracing of

a few of these curves enlarged longitudinally so as to have the vertical and longitudinal amplifications equal—about 1,000 times. It will be observed how the impressions are long, shallow depressions, very shallow at first, gradually becoming deeper towards the centre, and again becoming shallow towards the other end. In this aspect they exactly resemble the grooves seen in photographs taken of portions of the surface of the wax cylinder.

One of the chief difficulties in earlier experiments with this instrument was to secure that the point of the first lever always was in contact with the horizontal portion of the short arm of the second lever, and that, on the other hand, the pressure was not too great. If the mechanism be considered, it will be apparent that, supposing the grooves on the wax cylinder to deepen, as would be the case if the sound recorded became more intense, the whole of the aluminium lever would fall, and its point would pass too heavily on the arm of the second lever. On the other hand, suppose the groove to become shallow, as happens when the sound is less intense, the aluminium lever would rise, and, as it is rigid, its point might come off the horizontal arm of the second lever. In the first case, when the pressure was too great, the curves recorded on the paper would be less in height than they ought to be, and, if the point of the lever came off the horizontal arm of the second lever, or touched it with a series of knocks, either no curves at all were obtained, or the curves were not transcripts of the marks on the cylinder.

I endeavoured to meet this difficulty by turning the screw in the plate which raises or depresses the arm bearing, in the usual phonographic arrangement, the reproducing diaphragm, or, as in my instrument, the aluminium lever. Still it was difficult to do this accurately. At last the difficulty was got over by an automatic device. On the top of the screw for raising or elevating the aluminium lever, we fixed a round shallow drum, *r*, 80 mm. in diameter, and covered, on its outer surface, with sandpaper, so as to be rough. Then the cord passing from the electro-motor to the

phonograph for driving slowly the mandril bearing the wax cylinder, c^{IV}, was brought round a pulley, *s*, seen in Fig. 20, and then transversely in front of the side of the roughened drum, *r*. The cord then passed round another pulley, *t*, attached to the keeper of an electro-magnet marked *u* in the plate, and then back to another pulley passing transversely to the roughened drum and parallel to the first cord. It then passed round a second pulley, marked *v* on plate, then round the pulley on the phonograph, and back to the electro-motor. When the electro-motor worked, the cord moved slowly in front of the roughened drum, and one portion moved in one direction while the other moved in the reverse direction. If the lower cord, t^{I}, touched the roughened drum, it would be moved on, carrying the screw with it, in the direction say of the hands of a watch, but if the upper cord, t^{II}, touched the side of the roughened drum, then the direction of the rotation of the screw would be in the opposite direction. It will be evident that the one movement might lower the aluminium lever, while the other might raise it.

In the next place, to make the apparatus work automatically, a slender platinum wire, *w*, was attached to the aluminium lever, about 15 mm. from its point. This was caused to dip into a little trough, *x*, containing mercury resting on a horizontal metal arm passing out from the support bearing the aluminium lever, but immediately beneath the lever and parallel to it, *zz*. Below the pulley round which the cord passed there is an electro-magnet, and the pulley is so attached to the keeper of the magnet as to be oblique. When the magnet is not acting, the keeper is free, the lower cord touches the roughened drum, and the latter moves in a given direction. If, however, the magnet acts, the keeper bearing the pulley is pulled to one side, so as to bring the upper cord against the roughened drum, and the latter moves in the opposite direction. Thus the movement of the screw by which the aluminium lever may be raised or depressed is regulated by the roughened drum, and this again by the electro-magnet and the two cords. Finally, the electro-magnet is brought into action when the platinum wire

or the aluminium lever dips into the mercury. This diverts a portion of the current that drives the paper feeder into the electro-magnet, the latter then acts, and the upper cord is brought into play. The following is an account exactly of what occurs:—

1. When the reproducing point connected with the aluminium lever *sinks too low,* the wire attached to the lever dips in the mercury, the current is made, the armature is drawn forward, the upper cord presses on the rough cylinder, the cylinder with the screw turns in a direction against that of the hands of a watch, the bearer of the lever and the reproducing point are lowered, the reproducing point, pressing on the cylinder, therefore lifts the lever and *the free end of the lever is raised.* Again,

2. When the reproducing point rises too high, the wire attached to the lever is lifted out of the mercury, the current is broken, the armature falls away by the action of a counterpoise, the lower cord presses on the rough cylinder, the cylinder and screw are turned in the direction of the hands of a watch, the bearing apparatus is raised, the recording point on the aluminium lever is relatively lowered, and the *free end of the lever falls.*

By this arrangement, which may be called an automatic "finger and thumb" for turning the screw in reverse directions, there is a constant self-adjustment according to the depth of the grooves on the wax cylinder, which again corresponds with the varying intensity of the sounds.

Since the apparatus was brought to its present condition, I have been able to record the vibrations of the tones of several instruments, and also the tones of the human voice, both in singing and in speech. Illustrations of these I now show you, and they will be represented in two plates to be appended to this lecture when printed. It is important to remember that in these tracings 1 linear foot shows the vibrations occurring in about $\frac{1}{40}$th of a second.

First, with reference to speech, I wish to point out that when the record of a *word* is examined it is found to consist of a long series of waves, the number of which depends (1) on the pitch of

the vowel constituents in the word, and (2) on the duration of the whole word or of its syllables individually. There is not for each word a definite wave form, but a vast series of waves, and, even although the greatest care be taken, it is impossible to obtain two records for the same word precisely the same in character. A word is built up of a succession of sounds, all usually of a musical character. Each of these sounds, if taken individually, is represented on the phonograph-record by a greater or less number of waves or vibrations, according to the pitch of the sound and its duration. The pitch, of course, will depend on the number of vibrations per second, or per hundredth of a second, according to the standard we take, but the number of the waves counted depends on the duration of the sound. As it is almost impossible to utter the same sound twice over in exactly the same fraction of a second, or in the same interval of time, the number of waves counted varies much in different records. The rate per unit of time determines the pitch, the number the duration of the sound. In a word, these successive sounds blend into each other, and, in many records, the passage from one pitch to another can be distinctly seen. The speech sounds of a man vary in pitch from 100 to 150 vibrations per second, and the song sounds of a man from 80 to 400 vibrations per second. The sounds that build up a word are chiefly those of the vowels. These give a series of waves representing a variation in pitch according to the character of the vowel sound. In the record of a spoken word the pitch is constantly moving up and down, so the waves are seen in the record to change in length. It is also very difficult to notice where one series of waves ends and where another begins. For example, in the word *Con-stan-ti-nople,* the predominant sounds are those of *o-a-i-o-ill,* and the variation in pitch is observable to the ear if, in *speaking* the word, we allow the sound of the syllables to be prolonged. If we look at the record of the word (as seen in the seven lines in Plate I., reading from left to right), we find these variations in pitch indicated by the rate of the waves, or, as the eye may catch this more easily, by the

greater or less length of wave, according to the pitch of the sound. The consonantal sounds of the word are breaks, as it were, in the stream of air issuing from the oral cavity, and these breaks (I am not discussing the mechanism at present) produce sounds that have also often the character of vowel sounds. Thus, at the beginning of "Constantinople," we have, as will be observed on pronouncing the syllable very slowly, the sound *ŭkkō*. This sound is represented in the record by a series of waves. Then follow the waves of the vowel *o*. Next we have the sound *nn* (driving the air through the nose), also represented by a series of waves, and then the hissing sound *ss*, which has first something in it of the vowel *e* or *i*, and then the *iss-s*. This sound also is shown by a series of waves. Then there is *ta*, which has a double series of waves—first, those for *it* or *t*, and the next for *a*. This passes into the prolonged vowel *a*, this into *in*, this followed by *ti* passing into the vowel *i*, then another *in*, then a long *o*, then a sound like *op*, and, lastly, the sound *ill*, a sort of double-vowel sound. As so many of these sounds have the character of vowels, it is impossible, by an inspection of the record, to say where one set of waves begins and another ends. There are no such breaks corresponding to the consonants; the vibrations of the consonants glide on as smoothly as those of the vowels. The *number* of waves producing a word is sometimes enormous. In "Constantinople" there may be 500, or 600, or 800 vibrations. A record of the words "Royal Society of Edinburgh," spoken with the slowness of ordinary speech, showed over 3,000 vibrations, and I am not sure if they were all counted. This brief illustration gives one an insight into nature's method of producing speech sounds, and it shows clearly that we can never hope to read such records in the sense of identifying the curve by an inspection of the vibrations. The details are too minute to be of service to us, and we must again fall back on the power the ear possesses of identifying the sounds, and on the use of conventional signs or symbols, such as letters of the alphabet, vowel symbols, consonant symbols, or the symbols of Chinese,

which are monosyllabic roots often meaning very different things according to the inflection of tone, the variations in pitch being used in that language to convey shades of meaning.

When human voice sounds are produced in singing, especially when an open vowel sound is sung on a note of definite pitch, the record is much more easily understood. Then we have the waves following each other with great regularity, and the pitch can easily be made out. Still, as has been well pointed out by Dr. R. J. Lloyd, of Liverpool, a gentleman who has devoted much time and learning to this subject, it is impossible by a visual inspection of the vowel curve to recognise its elements. Thus two curves, very similar, possibly identical to the eye, may give different sounds to the ear—that is to say, the ear, or ear and brain together, have analytical powers of the finest delicacy. No doubt, by the application of the Fourierian analysis, we may split up the periodic wave into a fundamental of the same period, and a series of waves of varying strength vibrating 2, 3, 4, 5, &c., times faster than the fundamental, and the relative amplitude of each of these may be determined. If all these waves of given amplitude and given phase acted simultaneously on a given particle, the particle would describe the vibration as seen in the original curve. Dr. Lloyd, however, is of opinion that even a Fourierian analysis may not exhaust the contents of a vowel, as it does not take account of inharmonic constituents which may possibly exist. Hermann* and Pipping† have also been investigating the analysis of vowel tones, and their investigations have revealed many difficulties. Hermann experimented with the ordinary phonograph, and obtained photographs of the movements of the vibrating glass plate. His curves are small, not unlike those seen in Koenig's flame pictures. In many cases they have sharp

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* HERMANN. *Ueber das Verhalten der Vocale am neuen Edisonische Phonographen. Pflüger's Archiv,* Vol. XLVII., 1890; also *Phonophotographische Untersuchungen, op. cit.*, ii. and iii.

† PIPPING. *Om Klangfärgen hos sjungna Vokaler.* Discussed in Dr. Lloyd's paper on the Interpretation of the Phonograms of Vowels, *op. cit.*

points (Fig. 18). This, however, may not interfere with analysis. Pipping's curves were not obtained from the phonograph, but from the vibrations of a minute membrane made to represent the drum-head of the ear. His curves show large periodic waves with minute waves on their summits, and they suggest that the large waves may be vibrations due to the membrane itself. Not having seen the apparatus, and as the observations have been made by one well aware of the possibility of this error, I do not venture to do more than suggest this difficulty, especially as I now show you a series of tracings on a glass plate very similar to those in Pipping's figures. These were obtained by singing a vowel into a receiver furnished with a small membrane, to which a recorder was attached. The glass plate (smoked) moved rapidly across in front of the marker. Alongside of these you will see curves obtained directly from the recorder attached to the glass disc of a phonograph. In the second you see waves more like those of Hermann. The larger waves in the tracing, like that of Pipping, are, I believe, due, in my experiment, to the vibrator, and do not represent the glottal vibrations. This conclusion is strengthened by noting the pitch of the sound, as made out by counting, not the larger, but the smaller waves, which corresponds to that of the vowel sound. I therefore think that argument should be based only on records obtained from the phonograph itself, which is furnished with a vibrator that will not record its own periodic vibrations unless the sound be remarkably intense. In ordinary voice production and in ordinary singing, the vibrator of the phonograph faithfully records only the pressures falling upon it—no more and no less.

I shall now show you another method of recording, not the individual vibrations of the phonograph, but the variations in intensity of the sounds of the phonograph—the intensities of individual notes and chords. I was led to use this method by becoming acquainted with an instrument devised by Professor Heurthle, of Breslau. He has succeeded in recording the vibrations of the sounds of the heart. I saw that his instrument was very useful, and I

adapted it to the particular purpose in hand. Heurthle's instrument is an electro-magnet acting on a metal plate connected with the elastic membrane of a tambour. Another drum is connected with the first by an india-rubber tube. The metal plate of the first tambour is pulled down by the electro-magnet; thus the air is rarified in the tube and in both tambours, and the lever of the second tambour moves. The next instant the lever flies back. We shall now connect Graham's variable resistance apparatus with the phonograph. As sound waves fall on it, a change is produced in the current passing through the electro-magnet; the latter acts on its tambour; a variable pressure is communicated to the other tambour; and if the lever of the latter is brought against a revolving drum, a tracing is obtained. I show you a little bit of such a tracing.

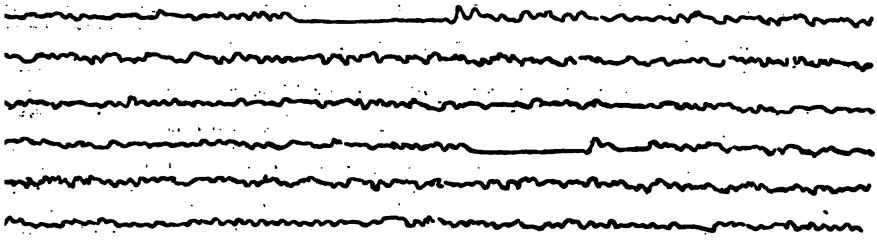

Fig. 21.—Portion of a record of the time and intensity of music played by a military band. Each curve represents a note or chord. The curves are read from right to left. The cylinder in which the record was taken was moving slowly, about 1 inch per second.

Each note and each chord are recorded, so that you get a mechanical tracing of the variations of intensity. Now this experiment suggested another of a different kind. Suppose I send the current not only through the variable resistance apparatus above the disc of the phonograph, but also through the primary coil of an induction machine. The wires from the secondary coil pass to two platinum plates dipped in weak salt solution. I now set the phonograph going; and when I put my fingers into the beakers containing salt solution, I *feel* the intensity of every note. The variation of intensity, the time, the rhythm, and even the expression of music, are all felt. I

shall now place on the mandril of the phonograph a cylinder on which has been recorded another piece of music, which is much quicker. I now feel a series of electrical thrills corresponding to every variation of intensity of sound coming from the phonograph.

That method shows that the nerves of the skin can be stimulated by irritations coming to it at the rate of the notes and chords of rapid music. Some of the notes produced by the phonograph do not last longer than the five hundredth or six hundredth part of a second, but they are quite sufficient to stimulate the nerves of the skin, and, as I have pointed out, you can appreciate the variations of intensity. You can *feel* the long drawn-out notes from the saxhorn or trombone. You feel the *crescendo* and *diminuendo* of rhythmic movement, and you can estimate the duration of the note and chord. You feel even something of the expression of the music. It is rather a pity to say that even expression is mechanical. It is undoubtedly mechanical when you deal with the records of the phonograph. A number of interesting questions of a physiological nature are suggested by this experiment. The skin is not a structure that can analyse tone or distinguish pitch; it cannot tell you the number of vibrations, although there is a curious approach to it. While it is not by any means accurate, you can distinguish tone of low pitch—very low tones—by a feeling of "intermission." Experimenting in this way, you may stimulate by interrupting this circuit at the rate of 30 or 40 or 50 breaks per second, and yet the skin will tell you the individual breaks; but when you get above that number you lose the consciousness of the individual breaks, and you have a more or less continuous sensation. The phonograph does not necessarily give you 50 or 60 *stimuli* to produce a sensation of a tone; you do not require that number. I found that 8 or 10 per second may give you the sensation for a tone of any pitch. In the same way you may be able to notice a slight difference up to perhaps 50 or 60, but above that the sensation seems continuous. It is not the number of *stimuli* that determine pitch, but the rate at which the *stimuli* affect the

sense organ, whether it be ear or skin. Then the question arises, What is it in the skin that is irritated? It is not the corpuscles. They have to do with pressure. There is no organ for the sense of temperature. You may say that the feeling is muscular. Possibly it may be so; but the effect is most marked when the current is so weak as to make it unlikely that it passes so deep as to reach the muscles.

This experiment suggests the possibility of being able to communicate to those who are stone deaf the feeling, or, at all events, the rhythm of music. It is not music, of course, but, if you like to call it so, it is music *on one plane and without colour.* There is no appreciation of pitch or colour or of quality, and there is no effort at analysis, an effort which, I believe, has a great deal to do with the pleasurable sensation we derive from music. In this experiment you have the rhythm which enters largely into musical feeling. On Saturday last, through the kindness of Dr. J. Kerr Love, I had the opportunity of experimenting with four patients from the Deaf and Dumb Institution, one of whom had her hearing up till she was eleven years of age, and then she became stone deaf. This girl had undoubtedly a recollection of music, although she does not now hear any sound. She wrote me a little letter, in which she declared that *what she felt was music*, and that it awakened in her mind a conscious something that recalled what music was. The others had no conception of music, but they were able to appreciate the rhythm, and it was interesting to notice how they all, without exception, caught up the rhythm, and bobbed their heads up and down, keeping time with the electrical thrills in their finger tips.

Lastly, I must say a word as to how the ear analyses such compound waves as we have been considering. Here are eight tuning forks, arranged in a harmonic series, Ut_2, Ut_3, Sol_3, Ut_4, Mi_4, Sol_4, Si (7), and Ut_5. I now sound all these, and you hear a rich mass of tone produced by a highly complex wave built up of the eight waves emitted by these eight forks. The ratio of the vibrations of these forks is 1 (Ut_2), 2, 3, 4, 5, 6, 7, and 8.

This compound wave traverses the air of the room and falls on the drum-head of your ear. You hear the fine rich tone; but pay close attention, and you will hear some of the tones comprising it; at all events, you will pick out of the mass of sound any tone that I make a little more intense than the rest, by gently bowing the corresponding fork. Listen. You now hear the tone of Sol_3, now that of 7, now that of the fundamental first tone, Ut_2. Suppose we had another set of forks at the other end of the room exactly tuned to these eight, when the compound sound wave floated over them, each fork, by sympathetic resonance, would pick out its own tone. In short, the eight forks at the other end of the room would analyse the compound wave sent out from the eight forks at this end of the room. Now, as we have the power of analysis—even musically deficient people have this power—we must have, in the internal ear, some kind of vibrators tuned to all the tones we can perceive, from 30,000 to 40,000 vibrations per second. The nerves are thus affected; the message goes to the brain; and we hear a tone, simple or compound, according to the nature of the waves falling on the drum-head of the ear. This, which is substantially the theory of Von Helmholtz, is, I hold, the only one that will in any adequate way account for the perception of tone. Behind the ear lies the brain. The messages ultimately reach it, but of what occurs there we know nothing.

The PRESIDENT (Dr. Eben. Duncan).—I am sure we have all listened with intense interest to this most admirable demonstration which Professor M'Kendrick has given us to-night. The occasion of this particular lecture is that 25 years ago, or thereabout, there was in Glasgow a committee of gentlemen who arranged a series of science lectures, and these gentlemen brought down to Glasgow all the most eminent scientists of the day, and I daresay there are many ladies and gentlemen present who had the privilege of listening to some of those science lectures. By-and-by the interest of the public or these gentlemen began to wane, and they handed over a sum of money to the Philosophical Society

in order to perpetuate these lectures in some fashion. From time to time, as our means afforded it, we have had the privilege of having lectures similar to the one that you have listened to this evening, and I am sure that Dr. M'Kendrick, who has done very many eminent services to the Philosophical Society, and who has been one of our most eminent members, has never done a better service to the Society than he has done to-night. He has given us the advantage of an enormous amount of investigation. These investigations must have cost many months of very great trouble and very great anxiety in the manipulation of these exceedingly elaborate instruments, and he has done to-night what you might expect some wonderful magician to do. He has made the eye do what it never was intended to do, and speech to do what it never was intended to do, and the nerves of touch to act in such a way that they can appreciate sound. I think we are all under a great debt of gratitude to Dr. M'Kendrick, and I hope that this is the beginning of the series, and that by-and-by the development may be still more wonderful and interesting. I have great pleasure in asking you to award him a very hearty vote of thanks for this most admirable demonstration that he has now given us.

DESCRIPTION OF PLATES.

PLATE I.—Curves taken with the Phonograph Recorder from records of concertina, flute, and of the word "Constantinople."

PLATE II.—Curves taken with the Phonograph Recorder from records of cornet, the sounds of quick-firing guns, the noises of a boiler-maker's shop, a soprano voice, bugle, bass trumpet, piccolo, euphonium, and military band.

NOTES.—Some of these curves are not sufficiently accurate for harmonic analysis, inasmuch as their periods are not exactly equal. They are given simply to show the great variety of wave forms imprinted on the wax cylinder of the phonograph. To obtain curves accurate enough for analysis, the greatest care has to be taken to have the tension of the